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ACOUSTIC EMISSION ANALYSIS AS A NON-DESTRUCTIVE
TEST PROCEDURE FOR FIBER COMPOUND STRUCTURES

J. Block



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| 14. Abstract Acoustic emission analysis is explained in scientific terms. The detection of acoustic events, their localization, damage discrimination, and event summation curves are discussed. A block diagram of the concept of damage-free testing of fiber-reinforced synthetic materials is depicted. Prospects for application of the concept are assessed. | | | |
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ACOUSTIC EMISSION ANALYSIS AS A NONDESTRUCTIVE TEST
PROCEDURE FOR FIBER COMPOUND STRUCTURES

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J. Block

Fiber reinforced materials are becoming more and more important, especially in aviation construction. The following contribution will present sound emission analysis as a method which can be used for non-destructive testing of fiber composite structures, and can be a useful complement to other methods.

Non-destructive testing of fiber composite structures

Technological use of the specific properties of fiber-reinforced materials is not a new procedure. For many thousands of years, humans have used it to manufacture components, to build vehicles and to build buildings by processing the wood found in nature. The easy availability of wood, its exceptional mechanical properties, its relatively easy workability and the fact that it has a small specific weight in spite of its high strength, made it the most used material up to recent times. Metal was only used for a long time for special products, such as weapons or tools. It is only since the Industrial Revolution in the previous century that metal products began to look like the material of the future.

However, today, considering the general availability of plastics and the fact that the ground raw materials are becoming scarce, all metals will be more expensive and less available in the future. In the ideal case, all components, both the fibers and the resin of the imbedding mass (matrix) would be manufactured from basic materials which are easily available and therefore cheap and could be combined to form laminate structures depending on the application. In addition, fiber materials are specifically lighter than metals, which in

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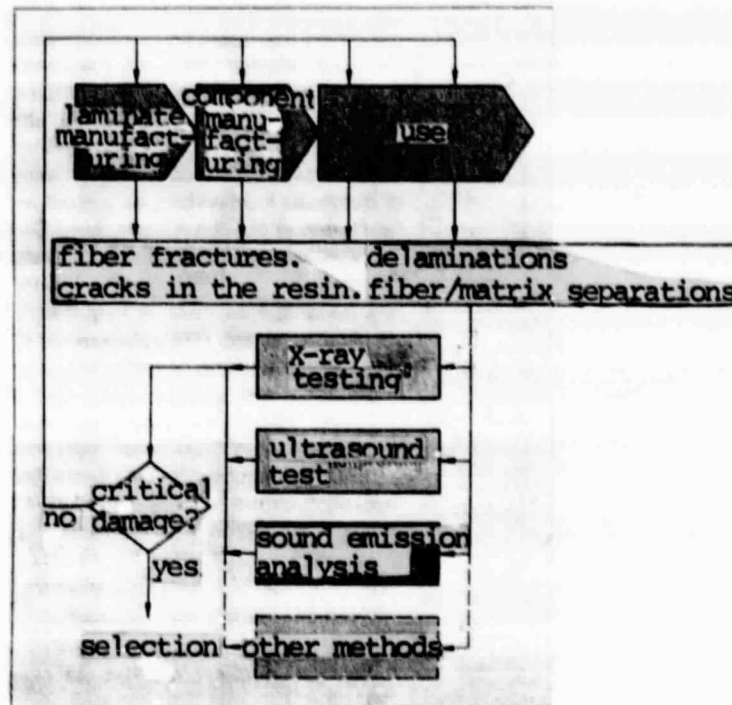


Figure 1. Concept of the non-destructive testing of fiber-reinforced plastics.

general, is an advantage if the technical product is to have buoyancy or has to be accelerated.

This means that fiber composite materials again are interesting for aircraft construction. In practice, however, there are a number of problems. One of these is the problem of non-destructive testing which is more difficult than in the case of metals and alloys because the internal structure is much more complex.

The damage which can occur under loads in the structure is much more complicated, for example, fiber and matrix fracture, separation between the fiber and the matrix or between entire layers

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(delamination). Non-destructive testing is supposed to give an exact picture of all of these defects if possible during testing, that is in real time. In addition, the testing should not produce any more damage (no falsification of measurement results due to the measurement process) (Figure 1). It is obvious that none of the known methods can satisfy these criteria in an optimum way at the same time. Several test techniques have to be combined for basic investigations.

Sound emission analysis

Sound emission analysis (SEA) is one of the non-destructive test methods and very often is simply called "sound emissions" (English "acoustic emission"). Strictly speaking, this is false. In contrast to ultrasonic testing, the test apparatus transmits nothing at all.

Instead, it has a completely passive function. It records noises which are created in the investigated sample, if stored energy is given off in the form of elastic waves there.

Sound emission of solid bodies is a well known phenomenon. All possible physical processes in metals, alloys, composite structures as well as amorphous solids produce noise in some form. One well known example of this is "tin screaming", a phenomenon in the twin formation in a tin crystal. It is only spectacular because it occurs with a relatively high intensity in the audible range of the spectrum. Most natural sound emission processes have too high a frequency or /35 are too weak to be recorded by ear. There is another possibility that they are not recognized because they occur so often, for example, the noises in the settling of wood.

The first sound emission phenomena where analysis was carried out was done in a frequency range which can be considered esoteric from the point of view of technical SEA. These were the earthquake

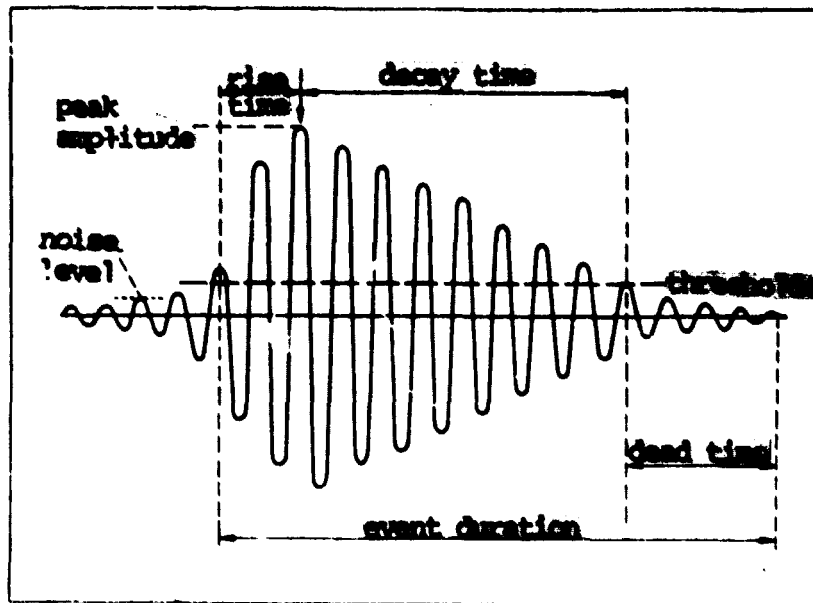


Figure 2. Signal scanning of a sound event

waves, infrasound emissions of the earth's crust and the earth's cover. All of the seismic processes occur in the range between about 10^{-2} Hz to 10 Hz. For non-destructive testing of materials and components, frequencies on the order of 100 kHz are used.

Up to recent times, the technical applications of SEA were restricted drastically. Essentially, it was restricted to the monitoring of extensive metal structures (tanks, refinery installations, reactor pressure vessels, pipelines, etc.) where the safety requirements were high and the amount of information process is small. Usually, the SEA facility only had to determine the positions of suspicious activities in the investigated objects. The analysis was done using other methods. It was only recently that advanced systems for sound emission analysis were developed which allow domestication of complicated structures as the laminates made of composite fiber materials mentioned above. In the investigations of the Institute for Structural Mechanics, all samples were made of carbon reinforced plastic (see CFK).

Sound event scanning

When elastic energy is suddenly released, sound waves are produced whose frequency distribution can be very wide. They propagate through the sample and are recorded by the sensors of the SEA installation. These are piezoceramic transducers which give off a voltage signal corresponding to the sound wave. It is then amplified and then can be analyzed. It is important that the sound emission can be resolved in time into individual events. If this decays into a continuous noise, then it is not possible to obtain meaningful correlations of measured parameter values. Then either the load rate has to be reduced or if this cannot be done because the load rate corresponds to the conditions of the test, the sensitivity has to be reduced. Figure 2 gives a picture of the scanning of a voltage signal produced by an individual sound event scan.

All signals which exceed a voltage threshold clearly above the noise level are converted to digital pulses. At the same time, the amplitude is scanned so that the rise time up to peak amplitude, the decay time as well as the total duration of the event can be determined.

The fixation of the events in an absolute time scale is also very important because the entire position determination technology is based on the possibility of correlating the damage processes in the sample with a load/time variation.

Neither X-ray nor ultrasonic technologies have this advantage. They only give instantaneous pictures of the sample with all of the damage which has accumulated up to the time the photograph is made.

Position determination technique of SEA

The simplest method of localizing a sound source with a sound emission analysis is linear position determination. Two senses are

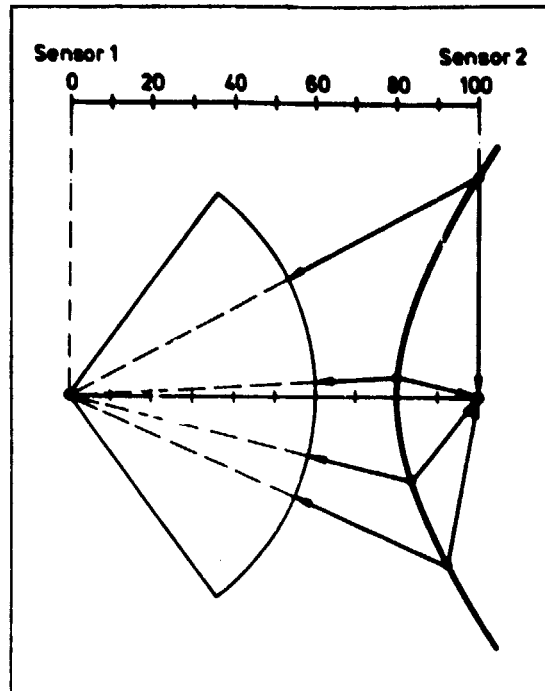


Figure 3. Linear position determination on a flat isotropic plate.

used for this. The electronics, of course, has to be designed for two simultaneously operating channels. Any acoustic event in the sample is then recorded in one sensor somewhat earlier than in the other. The system measures the time difference and relates them to the running time of the sound between the two sensors which were determined previously by calibration. The event is output as a fraction of the path between the sensors.

This method only is reliable when the sample is not only flat but also is elongated and narrow. Even if we consider the simple case of a flat plate, where the speed of sound is independent of direction (isotropic) and constant (which is never true for fiber composite materials), that is, when the running time and the path difference of the sound are equivalent, one obtains hyperbolas as the loci of equal running time difference. The sensors are then located at the foci of the hyperbolas (Figure 3).

The deviations in the position result from the true location and (referred to the axis) are only sufficiently small in the vicinity of the connection axis. This also is true for real laminates with high anisotropy (direction dependence) with respect to the speed of sound. This is because in the one-dimensional special case, the deviation of the position lines from the hyperbolic shape plays no role. The axis is intersected at the correct point.

This means that as long as the sensors are applied at the end of a long sample with not excessive damping, the position results are correct for composite structures as well. Figure 4 shows several event histograms over the length of a CFK sample with a slit running through one-half of the sample width in the center. The sample was loaded by increasing amounts in the longitudinal direction. The 136 distribution of the sound events was output for various load levels. The maximum in the center is caused by cracks which occur in the corners of the slot to an increasing degree. In addition, one can see a general growth of damage over the right sample half with increasing loads.

In the case of measurements with two-dimensional components and also with components which have a curvature in space, one can no longer disregard an isotropy if the planar position determination is done by triangulation, that is, with path-time measurements for a known geometry. We will see that this is not the only possibility. The transfer of the method of applying sensors in the corners of the network made of equilateral triangles and the valuation of the measurement data (running time differences) is difficult using suitable triangulation programs. It is difficult to transfer this to the SEA method. In contrast to measurements of a large metal tank, for example, it is necessary to consider the complicated sound transmission properties of the fiber complex. The determination of these transmission functions by measuring the damping, dispersion and other effects here also gives physical data about the sample structure and does not have to be interpreted only as an auxiliary aid for planar position determination. However, up to the present time,

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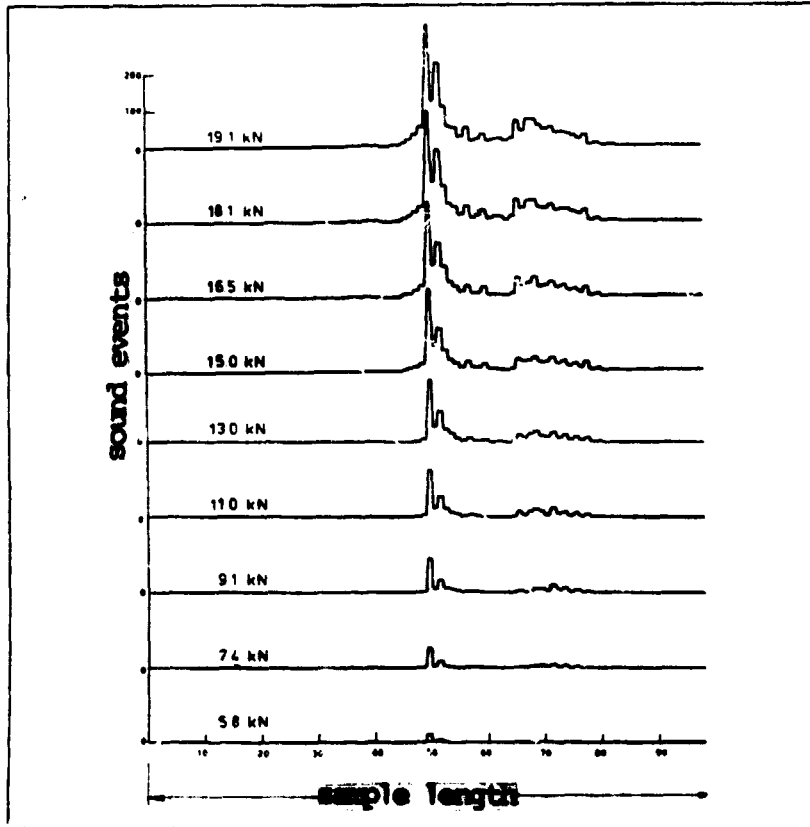


Figure 4. Load test with a long CFK sample. Position determination of damage with sound event histograms

there are no concrete results for this method.

The position determination using triangulation is made more complicated by the fact that the geometry of the sample can be very complicated (large curvatures, holes, edges). Another approach can be taken as shown in Figure 5. Then one does not become involved with the unknown transmission functions. Before the test, a large number of regions are defined where sound events are to be determined. Using a calibration sensor, sound signals of a suitable frequency are

injected into the sample. The measurement centers respond to them after a certain running time. Figure 5 shows how sensor 3 is affected first which starts a clock which again then measures the running time differences to the other sensors. This time pattern is stored. In a real test, then, every sound event which corresponds to the sample within large or small tolerance limits (shown in bright and dark colors in the figure) is associated with the corresponding zone around the calibration point. The certainty and uniqueness of this method, of course, increases with the number of sensors used.

Damage discrimination

By means of SEA, damage is not only located but should be classified according to various damage types. The main emphasis here is on the amplitude distribution of the sound event.

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In samples of rods made of various CFK laminates at the Institute for Structural Mechanics, it was found that the signals corresponding to fiber fracture had a substantially higher amplitude than those corresponding to pure matrix fracture. Up to the present time, it has not been possible to distinguish among the various weaker signals and the corresponding damage types. Crack edge friction and other effects have a disturbing influence here.

Event sum curves

Plots of sound events summed as a function of time, load or load cycle give interesting results. The beginning and variation of critical failure processes can be represented directly. In particular, the determination of the felicity effect gives information about the load history of the sample and under some conditions, can also predict its future load capacity (Figure 6).

The felicity effect is one variation of the known Kaiser effect. In metals, the Kaiser effect produces sound emissions only above the

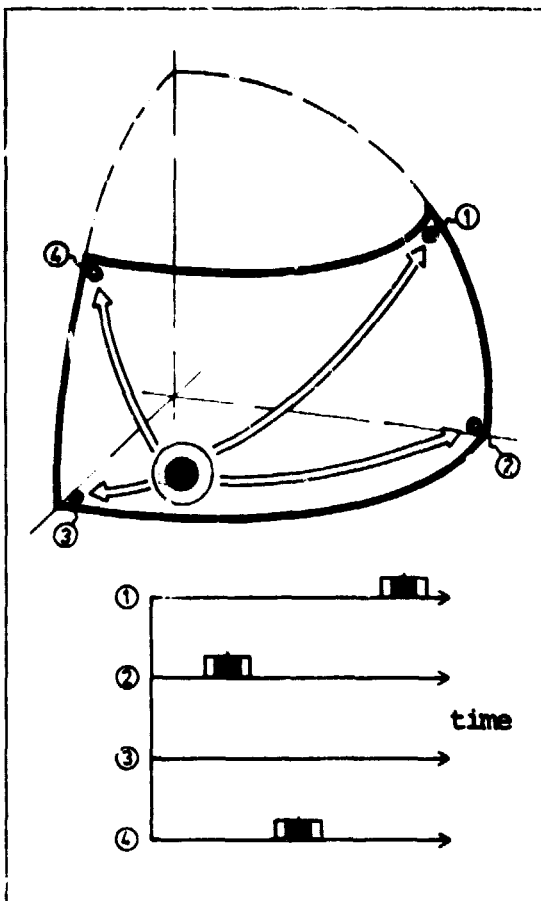


Figure 5. Planar position determination by running time difference pattern recognition.

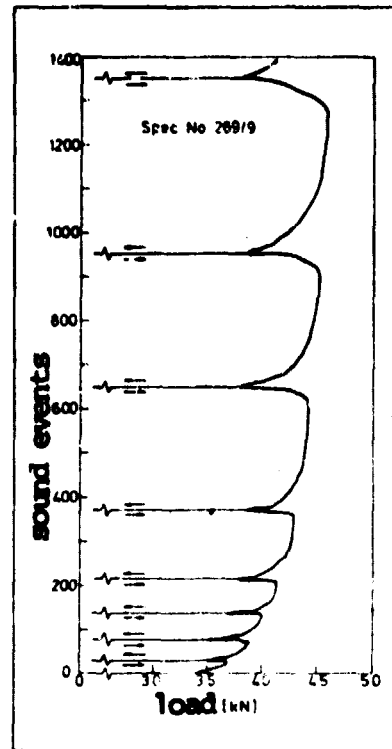


Figure 6. The sample was loaded and unloaded several times with continuous increase of the maximum load. The felicity curve is the sound event sum plotted over the load. It gives information for evaluating the state of damage of the sample.

maximum load to which the sample was subjected up to that time. In the case of composite structures, the emission starts before this. There are indications that the ratio of the load where this occurs and the maximum load will allow predictions about the fracture loads. In particular, by using the felicity curve of an unknown sample, one can determine how much it has been previously loaded.

The future

The use of SEA as a non-destructive test method for fiber composite structures is still in the beginning stages. However, many

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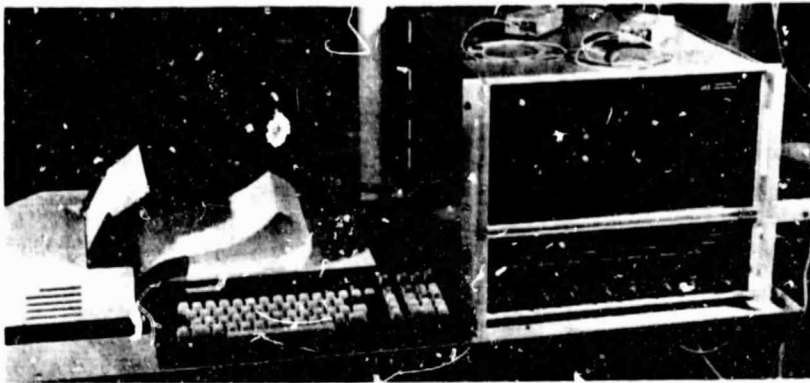


Figure 7. Programmable four-channel measurement unit for sound emission analysis. Two piezoceramic sensors with preamplifiers on the housing.

people are developing the method and standard test procedures are being developed. The device shown in Figure 7 at the Institute for Structural Mechanics is a typical prototype of a new generation of sound emission measurement installations which can be used for this today. Previous results indicate that sound emission analysis will in the future complement other test techniques in an effective manner. Here we have only outlined the possibilities.